EX POST IMPACT ASSESSMENT OF NRM RESEARCH IN THE ARID AND SEMIARID AREAS: THE CASE OF THE MASHREQ/MAGHREB PROJECT EXPERIENCE

SYNTHESIS OF THE TUNISAN CASE STUDY

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1. BACKGROUND

In the low-rainfall areas (annual average of 200-350 mm) of Maghreb and West Asia countries (WANA), small ruminant production (SR) represents the principal economic activity, contributing to rural incomes and national economies through the production of meat, milk, pelts, leather and wool. The traditional extensive production system was mainly based on the natural pastures, cereal straw, stubble grazing and barley grain. The region has experienced a substantial increase in livestock numbers over the two last decades (from 62 millions to some 80 millions), encouraged by increased demand for animal products combined with favorable price ratios between livestock products and barley. Feed subsidies and other measures intended to mitigate the effects of feed shortages in drought years have provided further incentives to retain greater number of animals. The consequences of this increasing population of SR in WANA is the drastic reduction of resource rangeland to cover feed requirement (Nefzaoui, 2002) and the increasing dependence of market and public support during drought conditions (Alary et al., 2002). This decreasing part of natural resource in the total feed resources resulted from several factors: demand, overgrazing, removal of vegetation by plough, soil erosion and land degradation. Inappropriate policies regarding land use and the absence of secure property rights have exacerbated the problem.

In this context, past and ongoing research attempts to identify available, or potential, technologies and management strategies for developing improved crop-livestock production systems, based on the integration of local and on-farm feed production combined with more efficient use of alternative feed sources and the improvement of livestock management, health, nutrition and reproduction.

In this process to address the development of sustainable and integrated crop/livestock production in the low rainfall areas affected by land degradation and poverty, the national programs of eight countries in the West Asia and North Africa (WANA) region (Algeria, Iraq, Jordan, Lebanon, Libya, Morocco, Syria, and Tunisia), ICARDA and IFPRI have implemented a collaborative research project on *Development of Integrated Crop/Livestock Production Systems in Low Rainfall Areas of the Mashreq and Maghreb Regions*, conveniently called the Mashreq/Maghreb or “M&M” project. The project has been supported by the International Fund for Agricultural Development (IFAD), the Arab Fund for Economic and Social Development (AFSED), the International Development Research Centre (IDRC), the Ford Foundation and the CGIAR System wide program on Property Rights and Collective Action (CAPRi) and the FEMISE (Forum Euro-Méditerranéen des Instituts Economiques). The M&M was initiated in 1995 and implemented in two phases, 1995-1998 and 1998-2002.

The research and technology development to improve feed and fodder production through-out the arable sector as well as from rangelands has been mainly focused on the feed block technology, the barley production, the stored forage in situ (Cactus, *Atriplex*) and livestock management. In this framework, the technology of the spineless cactus in alley cropping received the greater attention by the researchers, the development agencies and the farmers in the Tunisian community.

Donors and Governments of, particularly, North Africa countries have embraced the success of the M&M project and embarked on large development projects aimed to scale out this success. In Tunisia, the new strategy (2002-2011) of the OEP (*Office de l’Elevage et du Pâturage*), Office of Livestock and pastureland, forecasts to extend the technology to 44,000 ha. However, the impact of the project on farm income and on the natural resources has not been documented. The objectives of the ex post impact assessment are to:

(i) Assess the impacts associated with selected natural resources management technologies at communities within the “Mashreq/Maghreb Project”, ICARDA/IFPRI
(ii) Integrate socio-economic, technical and environmental indicators in assessing the impact of natural resources management research.

2. DEVELOPMENT OF THE TECHNOLOGY AND ICARDA INVESTMENT

Well adapted to the harsh environments of the dry areas, cactus represents an interesting production option for farmers as a feed source for the animals as well as providing a mean of protecting the natural resource base by controlling soil erosion and water loss. In Tunisia, if *Cacti* are well known such as the best plants for the reforestation of arid and semi-arid areas because of their resistance to scarce and erratic rainfall and high temperatures, alley-cropping systems are largely new phenomena.

Alley cropping is an agro-forestry practice where perennial crops are simultaneously grown with an arable crop. The practice is such that trees are grown in wide rows with crop grown in the inter-space. Alley cropping is a form of hedgerow intercropping. Leguminous and fast growing tree/shrub species are preferred for this practice due to their soil improving attributes i.e. nutrient recycling. In contrast to *Acacia cyanophylla* and other shrub species (e.g. Leucaena leucocephala, etc.), cactus is not a legume specie. Therefore, one would suspect the benefit from using cactus in alley cropping systems. The current project is to our knowledge the first, which is addressing the evaluation of spineless cactus-alley cropping system. Cactus may serve in this system as windbreak and water conservation, resulting to improved grass/cereal yields. Wide alley may allow animals to graze biomass strata or cereal stubbles in summer time. Cactus pads may be harvested and shopped into small peaces and given directly to animals as energy supplement of low quality stubbles. Properly managed, alley cropping can provide income at different time intervals for different markets in a sustainable, conservation orientated manner. Alley designs can also make better use of the space available between trees and add protection and diversity to agricultural fields.

The participatory approach through a strong partnership between a governmental agency (OEP), the research and the farmers is the main option followed in Tunisia in the implementation of such technology. The farmers' contribution consists on ploughing the soil, planting pads and maintaining planted areas for three years, while the government provides cactus pads (0,03 –0.04 US$ per double pad), the reimbursement of part of farmers' expenses [soil preparation (8,55 US $ per ha), planting (34,20 US$ per ha), provide subsidies (38,50 US$ per hectare per year for three years). The last subsidy is given in kind (concentrate feeds) and corresponds to 3 years period where livestock is prohibited to graze the planted area. This denotes the great effort made by the government toward the development of this activity in Tunisia. Using cactus in alley cropping seems to be a welcomed technique mainly in central and southern Tunisia. Therefore, the evaluation of this technology as scheduled in this project is expected to decide on the potential use of spineless cactus-alley cropping in arid and semi arid zones of Tunisia. Numerous countries may valuate these expected results.

The M&M Research Project provides scientific support to establish the technical system of alley cropping according to agronomic, ecological but also socio-economic characteristics of the community. The determination of distances between rows, the choice of the cactus species, the plant rate resulted from a progressive process with the community. The first in situ demonstrations (in 1997) propose 10 meters between rows. With the problem of mechanization, this distance has been extended to 20 meters in 1999-2000. Besides, some trials have been conduced on the impact of different cactus rations on the animal gain productivity.

Moreover the project proposes a participatory diagnostic with the governmental association in charge of pastureland (OEP), researchers and farmers' groups. This way of approaching the community facilitates the transfer of technology because of interactive discussions and adaptation of the technology to the real farm problems. Finally, the continuous visits of researchers between 1998 and 2002 in the community support its development although they are hardly quantifiable. Approximately, if the participatory diagnostic requires around 6 months for one community (or one village), it mobilizes only 4 researchers during 10 days. But if the diagnostic integrates the cartography, the household surveys and agronomic measurements, this approach requires approximately 4 persons during 2 months. In a scaling up objective of the technology, the intervention could be limited to the Rapid Rural Appraisal in the participatory diagnostic that requires 10 days with 4 researchers for one community (which counts around 500 households).

In summary, the main input of the M&M project was facilitating the new community-organization method of diffusion of new technologies and encouraging a broader based collaboration within the national society (Sanders et al, 2003). The community meetings with development agencies, public policy makers sometimes, farmers and researchers and the organization of regional workshop with farmers accelerate the diffusion of the technology.

3. RESEARCH METHODOLOGY

Introduction on major issues

The complexity of impact assessment study on the NRM research is the need to take into account the technical choices at the farm level and the agricultural and environmental policies and issues at the national or territorial level (such as soil erosion, soil degradation, water conservation). Technical choices are quite complex and depend on the decisions at the whole farm level (objectives, resource endowment, off farm opportunity, risk behavior, etc.) and the perception of the physical environment. This perception is a combination of experience (observation of productivity change) and trade off between present and future. This trade off is susceptible to change with household orientation (off farm orientation, return of the oldest son, for example) and resource endowments (land property rights).

If the classical econometric models based on statistical data allow approaching the determinants of adoption and the expected results in term of productivity and efficiency, they constitute limited approaches to integrate the complexity of the whole system with these three dimensions (socio-economic, bio-physical and environment) in a same schedule. Moreover the analysis of the impacts of NRM technologies implies to integrate the dynamic and the heterogeneity effects at the different time and geographical scales. In this framework, dynamic bio-economic models based on decision process models and bio-physical models offer interesting approaches. Their main advantages are to model competition, interactions and feedback effects between the different sub-systems (bio-physical, decisional and environmental) and the possibility to integrate various competing or complementary goals (marketing behavior, allocation of resource to farm and off farm activities, consumption choices, environmental) (Wyatt et al, 2001). These models have been applied and tested under various agro-ecological conditions (dry and humid tropical lowland and hillsides) in different countries (Alary & Deybe, 2005; Louhichi et al., 2004; Nordblom, 1994; Deybe, 1998). This modelling approach is currently being extended to many directions: a more detailed approach of farm types, development of risk coping strategies, procedures for aggregate analysis at the regional level (Kruseman, Bade, 1998), development of village/regional models to account for interlinked transactions and communal management of resources (Barbier, 1998; Alary et al, 2002), and the increasingly recognized role of off farm income in household decision-making process.

Swinton and Black (2000) discuss from 4 purposes of agricultural systems models: “description, prediction, *post diction* and prescription”. Descriptive models allow to characterize and to understand the system. The prediction or normative models propose some solutions on management of a system. Prescriptive or positive models describe what ought to be done and certain objectives are to be achieved at the individual or collective levels. “*Postdiction*” models which are used for analysis of past performance would be the more convenient for our objective. This means that using bio-economic models in an ex post impact assessment is not a new idea. But few research works use these models (mathematical programming models) in this way.

Methodology

This study aims to assess two specific impacts: economic impact at the household and community levels and environmental impacts. Our first objective was to couple two models: an economics model that represents the behavior of the farmers and a bio-physical model which will model the nutrient cycle and soil erosion in a framework of modular models. The Soil Changes Under Agro-forestry Model (SCUAF) developed by the International Centre for Research in Agro-forestry (ICRAF), has been identified. First simulations have been done with SCUAF thanks to data collection in 2004 on biomass production and soil analysis. But the calibration and validation of this biophysical model to represent the erosion process and biomass trends need more information on nutrient cycle and on the physical environment (especially soil characteristics) in the time. So we have preferred using “engineering production functions” in the economic model; these functions results from research on-farm trials *in situ*. In short, the mathematical model developed in the SPIA project doesn’t integrate the bio-physical model with environmental issues concerning soil degradation or water conservation. To approach the environmental impact with this model, we have used the “improved land area” as indicator. But cumulating the organic matter gain or soil saving over the period may overestimate the benefit of the technology knowing that the soil erosion indicators, for example, are not linear.

The economic model integrates the complexity of the activities at the whole farming systems, the individual technical and socio-economic constraints that limit or condition the adoption and the

common constraints due to social or economic arrangements in the community. This model includes four modules:
(i) Farm household module that specifies the underlying behavioral relations between household resource allocation and consumption priorities;
(ii) Input output module for crop and livestock activities that details technological coefficients for current and potential activities;
(iii) Optimization procedure to evaluate household responses to changes in the market environment;
(iv) Module of aggregation that tackles tradeoffs between individually owned production factors (mainly land and labor) and access to common resources at the community level.

The originality of this type of model is to represent interrelations between the different components of the farming system: livestock system and cropping system in term of resource supply/demand competition and/or complementarities and the interrelations between the socio-economical system, including fund management (cash flow, credit, etc.), and the bio-technical system that explain why farmers don't / cannot choose the technical or economic options considered as the best or the optimal. Figure 1 proposes a sample schedule of the model.

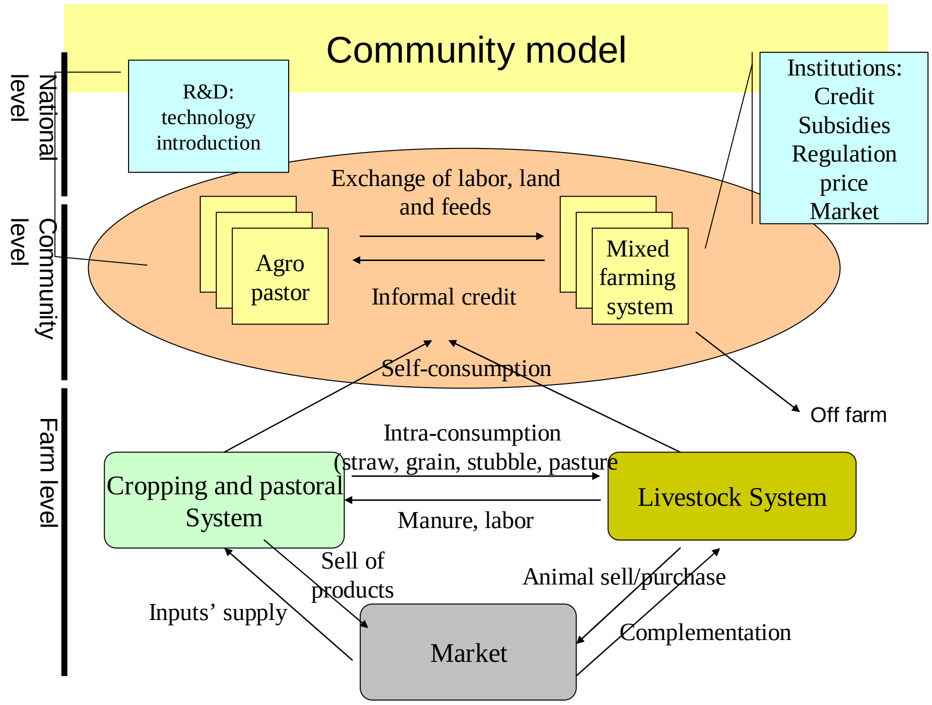

Figure 1: Schedule of the community model

The community model represents a simplified picture of an aggregation of typical whole farm systems. These typical whole farm systems are identified through cluster analysis on the database issued from the household surveys (Box 1). Each farm is characterized with its different resource endowments (land, labor and capital) and its management (crop and livestock systems, family objectives). The farmers interact among themselves through exchanges of factors, like non storable fodder, labor forces, land, credits. At the community level, the farmers are linked to the market for input purchases and output sales and the institutional environment for credit access or land and labor access.
The model developed relies on a standard mathematical programming formulation (Hazell et al., 1986; Boussard, 1971). Here it is the maximization of the expected net income function (including animal stock) under constraints of resource endowment and technical opportunities. To consider the trade off between the present and future, we developed a dynamic model over a planning horizon of 5 years. Risk behavior is one of the main factors to explain technology adoption. This risk behavior will depend on farms' characteristics (diversification, capital endowment, characteristic of the head of the family, etc.), the market conditions and the technology perception. The risk taking is formulated under the Target Motad approach proposed by Tauer (Tauer, 1983) at the individual level and the function is written as:

$$\text{Max } E(Z) = \sum_{ye=t_0}^{T} \frac{C_{ye} X_{ye}}{(1+\tau)^{ye}} + \mathbf{K}/(1+\tau)^{T} \text{ Avec : } A\,X_{ye} \leq B_{ye}\ ;\ B_{ye} = bX_{ye-1}\ ;\ X_{ye} \geq 0$$

Under risk constraints :

$$T - \sum_{j=1}^{n} C_{ye,j,r} \bullet X_{ye,j} - \lambda_{ye,r} \leq 0\ ;\ \ r = 1,\ldots,s\ ;$$

$$\sum_{r=1}^{s} P_r\, \lambda_{ye,r} = \Omega\ ;\ \ \Omega = M \rightarrow 0\ ;$$

$$X_j \geq 0, \lambda_{ye,r} \geq 0\ ;$$

where E(Z) is the objective function for maximizing, C_{ye} the vector of expected income from productive activities in the year (ye), X_{ye} the vector of activities' level, T the minimum target income, Ω Risk aversion coefficient according to Target MOTAD method, λ_{ye} the sum of negative deviations related to the income threshold (fixed for each farm type), T the planning horizon, τ the discount rate, A the input/output matrix and B_{ye} the matrix of available resources that depend on decision in the previous season (ye-1). The prices are exogenous and we suppose that the farmers take their decisions according to the prices of the previous year and the probability to have a good, medium or bad year.

The main structure of the model is presented in annex 2.

The main indicators generated by the model will be the farm income and the livestock trend for economic impact and improved land area for environmental impacts. Besides many other indicators are measured or calculated to deepen the analysis. Figure 2 presents the conceptual framework.

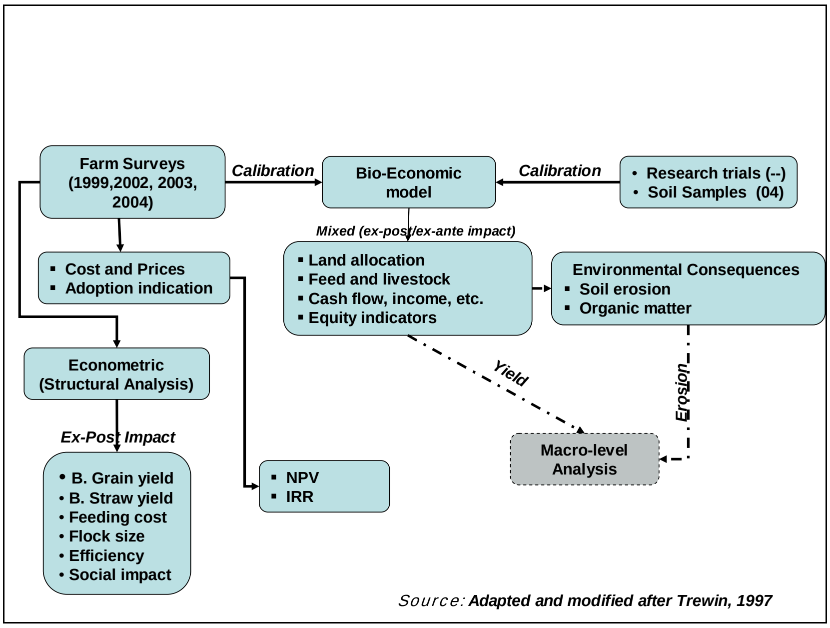

Figure 2: Conceptual Framework for Assessing the Impact of Cactus in Alley Cropping

According to Hazell and Norton (1986), calibration is used for the process of parameter setting and validation for a detailed comparison of predicted and actual outcomes. The setting of the risk aversion coefficient (Ω) is a part of the calibration and validation and allow to differentiate decision in certain environments and decision in uncertainty (Roumasset et al, 1979). The validation has been driven with the M&M team (to identify the key variables for the validation). A rapid survey has been conducted in

May 2004 in order to understand the reasons of some discrepancies between the results of the model and the survey for the 6 farm types represented in the model. This is the beginning of the analysis of the rationality or decision process of the farmers. The validation has been conducted considering that the farmers may benefit from the OEP project but the subsidies are limited. This will be the reference situation of baseline. The results are presented in Alary et al. (2004).

In a traditional ex post impact assessment study, the counterfactual situation would be the situation without the NRM project. This counterfactual situation is difficult to approach. In our case, the counterfactual situation corresponds to a scenario in which we suppose that the NRM project on spineless cactus in alley cropping has never existed.

The model has been mainly used for understanding and analyzing the adoption process by the different farm types at the community level. At this stage of research, this model has not been used in a participatory process to make discussed the farmers. But this community approach has constituted a tool to discuss the main determinants of adoption with the governmental agencies such as the OEP. In this way, the model could be an interface for discussing different issues of the technological process.

Box 1: Farm typology in Zoghmar community

This typology is an ascendant hierarchical classification based on multi-factorial K-tables analysis developed in the FEMISE Project and presented in an ILRI/ICARDA/USAID Project:

Young producers (EI2)
The type EI2 gathers young farmers (35 to 45 age years old) They own less than 15 ha with 1-2 ha in the irrigated perimeters. Olive trees occupy the rainfed areas and cactus the marginal cereal land. They cultivate intensively the irrigated areas with vegetable crops like tomato, melon, etc. To fund their agricultural activities, they often work as casual workers. The livestock activity is reduced to less than 10 ewes. The animal performances are low with less than 0.95 lambs per ewe and per year. These farmers haven't specific feeding strategies to reduce the impacts of droughts. Their main objective is to intensify the cropping system with the introduction of new crops in the irrigated areas.

Sedentary pastors or agro-pastors (EA1, EA2)
EA1 and EA2 types group all the farms which are mainly oriented to livestock activity. The ratio number of ewes/agricultural area is the highest and the total agricultural area ranges between 23 and 40 ha. If the sheep herd occupies the dominant place with more than 60 ewes, this type of farm counts also she-goats and cattle (between 1 to 4 cows). The cows cover the family milk requirements; the she-goats regulate the cash flow during the year, especially in summer. Sometimes, some farmers buy a veal calf which is bred under the mother. The feeding system is mainly based on barley straw and grain, hay, bran and cactus during drought years. These groups register good animal performances with more than 1.1 lambs per ewe and per year. The cultivated area is planted with barley for animal and durum wheat for family self consumption. It is observed that around 60% of used land is in jointly-owned property.
In this class, it is distinguishes two sub-groups:
1) The pastors (EA1) who affect the majority of land to barley and cactus (more than 8 ha is planted with cactus). This group has adopted the technologies introduced by the ICARDA project (M&M) such as the introduction of improved rams and the cactus to improve the animal performances.
2) The diversified agro-pastors (EA2) who affect more than 8 ha to durum wheat and 5 ha to olive trees, mainly as edge.

The mixed agricultural livestock systems with off-farm activity (EI1)
These farms are the largest agricultural farms with more than 50 ha and 3 ha are located in the irrigated perimeter. The main source of funding to invest in agriculture comes from off-farm activities. These are large families with more than 10 members, 7 at school. This class benefits also from bank credit. They are well-equipped with a tractor and a car.
The irrigated area is mainly affected to fodder crops (oats, sorghum) and cereal crops (barley and wheat) to cover the feed requirements. The average herd size is between 20 to 52 ewes. But these farmers don't register high performances with a productivity of 0.95-1.05 lambs/ewe/year.

The diversified herders (EA3, EI3)
These farmers have less than 9 ha without any property rights. The area is mainly affected to barley. These farmers have a diversified herd with 10 to 20 ewes and 5-8 she-goats. With a small family and without any other source of funds, the schooling rate is the lowest.
In this class, two sub-groups may be distinguished:
1) The old herders –with more than 65 years old- (EA3), who devote the small own land to the livestock. They register the best animal performances with a low use of hay and an important use of cactus in the feeding system.
2) The diversified herders (EI3) who have ewes and goats.
These two groups are seen different during the dry years: if the group EA3 de-stocks, the second group EI3 tries to keep his herd by increasing the cactus ration and temporary off-farm activities.

4. DATA SOURCES AND COLLECTION

The case study is the Zoghmar community, Central Tunisia, the area covered by the "Mashreq/Maghreb Project" (ICARDA project). This community is located in dry lands characterized with less than 350 mm rainfall and periodic droughts. Agro-pastoral systems are dominant production systems, and people derive their incomes from both livestock and crop production. In this area, the spineless cactus in alley cropping represents an interesting opportunity and could effectively substitute the traditional fallow cropping system.

Over the course of the project, Rapid Rural Appraisal (RRA) techniques including focus group discussions with the community, key informants and individual interviews were conducted, and used to choose and characterize the communities in the region, identify and understand the opportunities and constraints that communities and farmers face, and determine their main tactic options in the short term and strategies in the long term that explain farmers' overall behavior and decisions. All this information will participate to identify and characterize the community.

Data used for the adoption study on the cactus in alley cropping are collected from cross sectional sample of farmers within the targeted area and exhaustive survey conduced within the M&M Project and FEMISE project. OEP monitoring will complete the information.

The sample farmers used are selected on stratified random sampling, depending on the main farming systems in the area. These surveys give an (unbalanced) panel data of 45 farm households from Zoghmar community, surveyed in 1999, 2002 and 2003 (Table 1). Household surveys were conducted at the plot, farm and household levels to develop a database for the community model and econometric analysis. Crop and livestock monitoring activities were performed in order to gather data on the farmers' practices and productive performances and establish "engineering production functions".

Within the SPIA project, supplementary information from trials and related to slope, soil moisture, soil PH, soil organic matter content and biomass produced from cactus, crops and natural vegetation were monitored on 4 types of plots differentiated by the treatment: 1) Natural rangeland, where no intervention has been made, 2) Barley field using only farmer practice (no fertilizer application), 3) alley cropping cactus with no cropping between rows and where only natural vegetation is growing and 4) Alley cropping cactus with barley between rows. Here also, barley receives no fertilizer and is conducted similarly to treatment 2.

Two complementary farm surveys have been conduced in April 2004: 1) the first one aims to determine the economics and technical performances of the technology at the plot level; 2) the second aims to analyze the responses of farmers to different subsidies levels to implement the technology following to the method of contingency.

Table 1: Survey systems: samples and collected data in the Zoghmar Community (Tunisia)

	Survey 1999	**Survey 2002**	**Survey 2002**	**Survey 2003**
Source	M&M/ICARDA	M&M/ICARDA	M&M/ICARDA	FEMISE II/ICARDA
Household sample	39 farm	38 farm	318 farms (exhaustive survey)	34 farms
Plots sample	280 plots	197 rainfed plots 26 irrigated plots	371 pastureland 888 cultivated areas	
Head of the family/ household	Age, date of installation, off farm income, Family expenditure (health, food, school fees)	Age, date of installation, education, family component, off farm income, Family expenditure (health, food, school fees)	Age, date of installation, education, family component, off farm activity House, electricity, water	Age, date of installation, off-farm income
Structure	Equipment: Tractor Temporary or permanent workers, Area, livestock 99,98,97	Material equipment Building External salaries Area, livestock 01/02	Material equipment Building Area, livestock 1995 2002	Material equipment Building External salaries Area, adult animal stock 00/01,01/02,02/03
Crop management	Barley, wheat: seed, other inputs, production Sold and self consumed quantity	crops: seed, other inputs, production Sold and self consumed quantity	Cropping systems, varieties, water access Toponymic and plot characterization (slope, fertility, etc.)	Cropping system Production Sale and self consumption
Livestock management	For 16 farms :mating, lambing, twinning, mortality For all : - Consumption of barley grain, bran, hay, straw - charges ("achabat", watering, veterinary, other) - Grazing	Movements (purchase, sale, mortality, self consumption) between march 2001/2002 Consumption of barley grain, bran, hay, straw Feed purchase	Consumption of barley grain, bran, hay, straw Animal marketing	Movements (purchase, sale, mortality, self consumption) between march 2002/2003 Fattening system from march 2002 to march 2003 Consumption of barley grain, bran, hay, straw Feed purchase
Plots data	Area characterization (soil, fertility, salinity, soil nature), rotation, varieties, fertilization, yield, sale, consumption, property right, irrigation	Varieties, seed, harvest	For pastureland: Management (plain cactus, cactus in AC, *Atriplex*)	
Calculated Data	Family expenditure, animal feed purchase, water charges, cereal production	Family expenditure, animal feed purchase, water charges, cereal production Farm Budget		Family expenditure, animal feed purchase, water charges, cereal production Farm Budget

5. ADOPTION OF INTRODUCED TECHNOLOGY

In this section, two objectives are followed: 1) the determination of the levels of adoption through the adoption indicators and 2) the analysis of the determinants of the adoption. Different methods are called upon from basic statistics to econometric, method of contingency and community model.

5.1. Adoption of cactus in alley cropping at the community level

To approach the success of the technology, two indicators are usually used: 1) the rate of adoption that measures the number of adopters in the total population and 2) the degree of adoption that measures the total area affected to the technology on the total potential area. The potential area for the technology comprises 55% of the cereal lands and all the fallows. The potential rangeland is only 10% of the rangeland area because of this degraded status. We consider that the farmers are not going to root up spine cactus shrubs. We have used the exhaustive survey at the community level (M&M/ICARDA, 2002)

At the community level, the adoption rate is around 30.6 % with a degree of adoption around 29.7% in 2002 for all the community area, only two years after the introduction of the cactus in alley cropping. In reality, the degree of adoption might be higher considering the parceling and the soil conditions that reduce the potential area.

On the sample of 40 households, it is observed an increase of adoption rate between 2000 (37.5%) and 2004 (40%); the moderate decrease of adoption rate in 2001/02 is essentially lied to the drought years that affect cactus plantation. Moreover during these drought years, farmers use intensively the young plantations to maintain their sheep herd.

5.2. Who adopt the cactus?

The average surface planted with cactus increases with farm size reflecting the capability of farmers to release a part of their land for cactus cropping (Table 2). The average cactus area is around 10 ha for large farms (more than 15 ha) and decrease to 1.5 ha for small farms (less than 5 ha). And the rate of adoption and the degree of adoption decrease also from the large farms (61.3 % and 43.2 % respectively) to the small ones (13% and 14.5%).

If the total area planted with cactus in alley cropping seems well distributed between the different classes of farmers according to flock size, the large size shepherds who represent 8.2% of the population have planted 20.7% of the total cactus area.

Table 2 - Adoption indicators according to the farm and flock size (318 households)

Indicators according to farm size			Indicators according to flock size		
Farm size (in ha)	Rate of Adoption (%)	Degree of adoption (%)	Flock Size (heads)	Rate of Adoption (%)	Degree of adoption (%)
> 20 ha	61.3 %	43.20%	> 50	46.15%	36.83%
[20-10[ha	41.0 %	24.56%	25-50	38.18%	35.31%
[10-5[ha	34.5 %	23.54%	15-25	36.07%	26.99%
[5-1[ha	12.6 %	14.51%	< 15	25.83%	22.62%
Landless	0.0 %	--	No shepherd	20.00%	21.23%
Total	30.6 %	28.99%	Total	30.60%	28.99%

In the same way, the rate of adoption and the degree of adoption decrease from the larger shepherds (46.15% and 36.8%, respectively) to small shepherds (25.8% and 22.6%). We can observe that farmers without animals adopt the technology. 20% of them have adopted the technology on 21.2% of the potential area. This could reflect the attractiveness of the technology in term of new market opportunities but also the search of fund support as such as incentives. Most of these farmers were also small farmers who have lost their animal capital due to the drought years.

This finding reflects the various strategies adopted by farmers' categories which are described in the typology (Table 3), that has been used in the model. The adoption rates are the highest for the agro-pastors and the pastors; this is mainly due to the attractive cost and nutritious intake of cactus as a feed. The second groups are the diversified agro-herder and the multi-active, who are relatively the most interested by new technologies. The more reserved are the youngest and the oldest. But these two groups are obliged to make priorities and prefer to allocate land to food crops.

Table 3: Adoption level according to farming systems (Survey 2002; sample: 35 households)

Typology	Farms' number	Adoption (number)	Adoption (in %)
(EI3) Diversified Agro-herder	4	2	50
(EA2) Agro-pastor with olive trees	7	5	**71.42**
(EA1) Agro-pastor	5	5	**100**
(EI2) Young farms	5	1	20
(EI1) Pluri-actives	6	3	50
(EA3) Mixed farming systems	8	2	25
Total	***35***	***18***	***51.43***

In conclusion, one can say that non adoption is mainly due to lack of land or livestock. The adopters count in average 19 ewes and 11.5 ha of cultivated lands, against 12 and 8 for the non adopters. Moreover the adopters have 5.6 ha of pastureland, against 1.6 ha for the non adopters. Without market opportunities for pads and fruits, the technology remains attractive only for large or medium herders to face to drought periods.

5.3- The determinants of the technology adoption and impact of policy subsidies

In order to explain the determinants of the technology adoption, a censored regression is implemented. Acreage of cactus in alley cropping plantation (AC) is explained by a bundle of farmers' characteristics variables:

$$AC_i = \sum_j z_{ij} = f(A, L, Y, REV, F, AGE, INST, IR) \quad (1)$$

Where: z_{ij} is the i^{th} farmer's socioeconomic set of variables i.e. total owned land (A), labor allowed to livestock activity (L), sample mean small ruminant flock size (Y), off-farm income (REV), size of the household (F), age of the family head (AGE), a dummy variable indicating whether the head of the family is instructed or no (INST), and another dummy variable indicating whether irrigation is adopted or no (IR). In the present context, the dependent variable is only partially observed. Indeed, desired adoption rate may be censored at a small positive or zero value. Hence use of tools to perform maximum likelihood censored regression is straightforward.

Three variables are found to have a significant positive effect on the ability to adopt cactus in alley cropping technology: total owned area (A), the age of the head of the family (AGE) and the presence of an irrigated acreage (IR) (Table 4). For large farms, cactus plantation is a way to extend cultivated land, or at least to have an available fodder stock. Moreover with irrigation, some farmers prefer to reduce cereal production on rainfed area and save family labor for irrigated area. So cactus plantation is a way to maintain cultivated the rainfed land.

Table 4: Censored regression (dependent variable: acreage of cactus in alley cropping)

Method: ML - Censored Normal (TOBIT) (Quadratic hill climbing);Included observations: 33; Left censoring (value) at zero

	Coefficient	**Std. Error**	**z-Statistic**	**Prob.**
Intercept	0.3437	16.475	0.0208	0.9834
A (total owned area)	0.7811	0.2307	3.3858	0.0007
L (labor for livestock activity)	-5.2940	3.1171	-1.6983	0.0894
Y (Flock size)	-0.0484	0.0517	-0.9361	0.3492
REV (Off-farm income)	0.7282	0.6631	1.0980	0.2722
F (household size)	-4.5758	1.3472	-3.3963	0.0007
AGE (age of family head)	0.7813	0.2516	3.1050	0.0019
INST (degree of instruction of family head)	-9.7073	5.4707	-1.7744	0.0760
IR (irrigation or no)	19.829	6.3850	3.1055	0.0019

At opposite, three variables seem to reduce the probability of technology adoption: labor allowed to livestock activity (L), the household size (F) and the instruction dummy variable (INST). Labor allowed to livestock activity represents a constraint on labor availability to implement cactus plantation. The negative effect of the household size remains partially troublesome. One possible explication can be the fact that large size households prefer to promote hard wheat cultivation in order to ensure self-consumption. The result of the instruction dummy variable implies that farmers with a certain level of instruction are likely to practice fattening activity, based basically on feed, instead of herding.

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An additional survey has been conduced to determine the wishes of implementation of the technology for different level of OEP support. This survey (40 farmers surveyed in May 2004) is based on the method of contingency. Four subsidy arrangements have been proposed: 1) Adopting without any subsidy (A0); 2) Adopting with free access to spineless cladodes (A1); 3) Adopting with free implementation (subsidies cover cladodes supply and implementation) (A2); 4) Adopting with free implementation and 150 kg feed extra-subsidy per ha planted (A3).

Totally the potential increase of cactus area (from the declaration of the 29 farmers) is 122.5 ha. 42.4% of this area could be planted only if OEP distribute cladodes and 64.5% if OEP reimburse the cladodes and implementation cost (Figure 3).

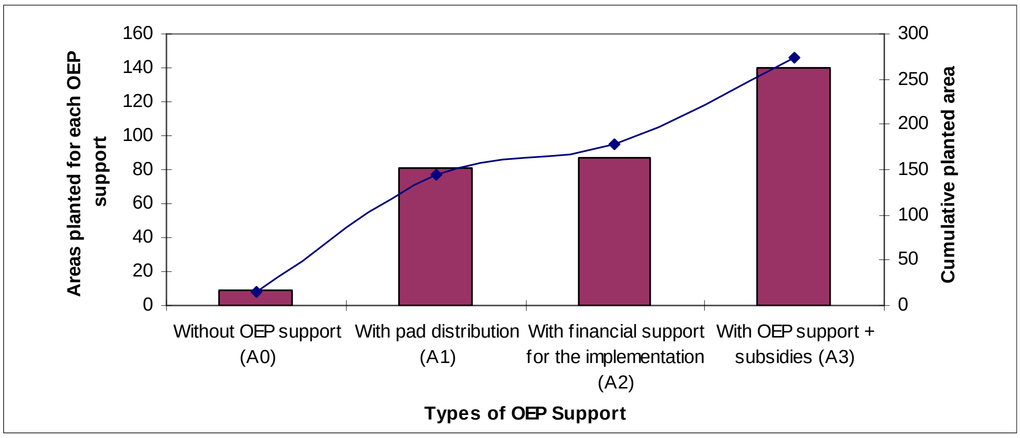


Figure 3: Cumulative planted area with the technology according to the OEP support (in ha) (Source: SPIA Survey, 40 farmers, may 2004)

These results demonstrate the ambiguous role of the subsidies in the decision process. We must mention that these intentions are declared in 2004 (that is a very good year) and they could be very optimistic.

5.4. Dynamic approach of the impact of the institutional environment on the level of adoption

The adoption of the technologies depends on many factors at farm, community and institutional levels. Generally the interrelations of these factors explain the adoption or no of a new technology. The farm factors include structural and functional components but also social components (characteristics of the family head, family requirements, family labor, off farm activities). The community factors include social aspects (social control, herding behavior) and economic aspects (exchanges of factors like pads at the community level). The institutional environment (including policy) refers to livestock and agricultural policies that can encourage or discourage the farmers as well as the land access that can influence the investment decision of the farmers. *Vice versa* the impacts of policies will vary according to the technological opportunities in each area. The community model offers a good opportunity to test the level of adoption of the technology according to different levels of subsidies.

In the first simulations, we evaluate the impact of the institutional actions, especially the subsidies and the technical support to implement the technology. In the simulations S1 and S2, it is supposed that farmers have accessed to the technology without any support (such as scenario A0, fig. 3). We assume two levels of expected yield: 1) (S1), the expected yield remains unchanged; 2) (S2), a 30% increase of cereal yields that corresponds to the registered yields[1]. In a second step, we introduce the institutional support that covers the pads' purchase, the costs of implementation and the subsidies (such as scenario A3, fig. 3). The simulations S3 and S4 are respectively without and with the cereal yield increase. The subsidies are distributed for the 3 first years of plantation. The support is limited for each farm type according to livestock and the area. In (S5), there is no restriction on OEP support. The first results (Table 5) show the different levels of adoption of the technology with and without subsidies.

Table 5: Adoption level for the different scenarii (area planted in cactus in alley cropping in ha)

	S1	S2	S3	S4	S5	Survey	
Farm type	Adoption level without OEP incentive	Adoption level without OEP subsidies+ 30% yield	Adoption level with limited OEP support	Adoption level with limited OEP support And yield increase	Adoption level with no restricted subsidies	Area of cactus in alley cropping	Area with spine cactus
C1	C2	C3	C4	C5	C6	C7	C8
EA1	0	5.78	5	16.53	16.5	5	8
EA2	0	2.93	1	2.93	2.9	1	2
EA3	0.29	3.34	3.34	3.34	11.4	2	2
EI1	10.21	29.17	30	45.6	50	30	
EI2	2.67	3.85	2.67	3.85	5.5	0	0.5
EI3	0	10.75	5	11.23	14.25	5	1

The scenario (S3) corresponds to the real situation with the limited OEP support and it is considering as the baseline scenario. Comparing to the survey results (C7), we note that the model in the baseline scenario gives a good approximation of the reality.

Without OEP support, three groups of farmers invest in the technology in S1 (with no yield change). Firstly it is important to note that the group EI1 was the only one not having spine cactus plantation in the farm. This group represents also the more comfortable group in the sample with a secure off farm activity in the administration and 4 ha in the irrigated perimeter. This high level of adoption confirms the precedent result that irrigation is a determinant of adoption. The group EI2 invests also in the technology at opposite of the reality. This gap between the reality and the simulation may be explained by two factors:

1) First, the farmers are reluctant to implement themselves the technology knowing that they can receive subsidies.
2) And, the information about the technology. Some farmers told us that they have seen the new plantations but nobody is come to introduce it. They are not aware about the yield increase' expectations, especially for the farmers with a small flock size.

In the scenario without the subsidies but with good yield expectations (S2), all the farm types adopted the technology. We can observe the similitude of plantation areas for the large farmers (EA1 and EI1) between the simulations and the observations (C7). That is explained by the important power of negotiation of these types (flock size, good management, etc.) to plant what they want, compared to small farmers. However, these results may suggest that without subsidies and well informed about the productivity gains, farmers may implement the technology on the majority of marginal cereal lands.

In (S3), the OEP support is limited for each farm according to flock size. Only the farm type (EI2) implement the technology without the subsidies and the group EA3 plant 1.34 ha more with the technology and without any subsidies. With the increase of expected cereal yield, all the farmers implement more than the subsidized area and fund by themselves the rest.

In (S5), all the farmers increase the acreage for spineless cactus in alley cropping about three times, compared to baseline scenario. The results show the interest for the technology with the financial support. But the similitude between (S4) and (S5) shows that good information about the yield

[1] The cereal yields estimated from on farm trials in 2004 are the first measurements of the expected cereal yields with the technology in Tunisia and will serve as reference in this study.

expectation with the technology ought to have the same importance than subsidies. It is true that the reality is more complex:

1) the expected subsidies can be more crucial, especially considering that during dry years, the expected yield of cereal in alley cropping could be inferior to the subsidies
2) Why implement alone this technology if we could profit from subsidies and yield increase in the same time? So some farmers are waiting.
3) As if the research extend their experiences to obtain relative “good information” about expected yields from this technology, it is not necessary that farmers might have access to this information; besides, the believe in this information will depend on the source of the information and the experience of the farmers.
4) Personal perception about the information is more important in the farmers’ decision process than given information about the technologies.

6. ANALYSIS OF IMPACTS

The objective of the SPIA project is to take into consideration the different domains (socio-economic, technical and environment) in assessing the impact of natural resources management research.

6.1. Output increase

Table 6 shows the first results of barley yields observed on a sample of 5 plots for each treatment: 1. Barley only; 2. Barley in alley cropping with cactus. All the other inputs held constant between the treatments in these comparisons. The estimations have been done in April 2004 with the grains at the milky stage. The total biomass yield increased from 4.24 T/ha to 6.648 T/ha, corresponding to an increase of 57 % due to an increase of 29 % of herbs (weeds + straw); but mainly to the dramatic increase of grain yield (171 %).
However, changes in yields were highly variables, and the number of sample needs probably to be increased to reach a better level of accuracy. Thus, the coefficients of variation of total biomass yields were, 39 % and 26 %, for alley cropping and plain barley treatments, respectively. Grain yields were even more variable within alley cropping treatment (47 %) compared to plain barley with a coefficient of variation of 18 % only.

Table 6: Barley yield with and without the technology (research trials: April 2004, Zoghmar, Sidi Bouzid)

Treatments	Herbs + grains (T/ha)	Grains (T/ha)
Cactus + Barley	6.648	2.232
Plain barley	4.24	0.824

On the natural rangelands, the herbaceous biomass yield is estimated at 4.98 tons/ha, compared to less than 3.3 tons/ha without cactus. The maximum attains 7.6 tons/ha in the alley cropping systems.
This result is obviously due to the micro-environment created by alley cropping. Indeed, cactus plants play as “wind breaks” that reduce water loss and increase soil moisture, which increases barley grain and total biomass yield. Also, cactus plants play a role of trap to several “moving seeds” creating a kind of niche to the emergence of interesting pasture species. These effects, even experimentally accepted, need further investigation.
Cropping barley between lines of cactus does not have a detrimental effect, which can result from competition to available moisture and nutrients, of cactus total biomass (pads + fruits) yields. Indeed, fresh biomass yields of total cladodes (cumulative of 3 consecutive years) are estimated to 118 and 132 tons/ha, respectively for cactus without and with barley intercropping (Table 7). Fruit production follows the same trend. Also, these particularly high yields are the result of two consecutive favorable years.

Table 7: Cactus yields for the two treatments: cactus on natural rangeland and cactus with barley

		Pads	Fruits
Cactus on natural rangelands	Average number of pads or fruits/plant	59	44
	Standard deviation (unit/plant)	24	24
	Average per ha (en Tons/ha)	**118.4**	**8,73**
Cactus with barley	Average number of pads or fruits /plant	66	88
	Standard deviation (unit/plant)	33	47
	Average per ha (en Tons/ha)	**132**	**17,69**

This result explains the high increase of above biomass with barley in alley cropping (7.11 Tons/ha), compared to the treatment cactus alone (1.87 Tons/ha) (Table 8). Moreover cactus constitutes an important role to increase the under ground biomass in the soil. This increase should activate the biological live and then the organic matter of the soil.

Table 8: Biomass change according to the treatment (Tons/ha)
(Biomass estimated on the plot with barley only is constituted with weeds and stubbles after harvest)

Treatments	Above aground	Under ground
Natural rangeland (no barley, no cactus)	0.51	0.33
Barley (no cactus)*	0.53	0.11
Cactus without barley	1.87	1.8
Cactus with barley	7.11	1.98

All these data related to biomass and yield estimations have been collected during the SPIA project on only 5 plots in the community. Now, it is important to validate these results at a largest scale. But these first data give some qualitative ideas about the expected agronomic impact of this technology.

6.2. Input saving: reduction of market dependence during drought conditions

Measurement of animal performance

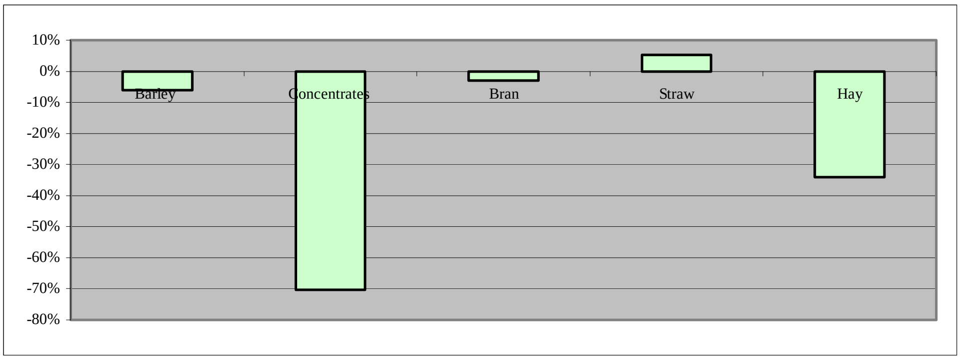
Numerous experiments were carried out along with the last ten years on the potential use of spineless cactus pads (cactus) in sheep and goat feeding. On-station trials were performed in semi-arid zones, which have quite similar conditions than those in target zone of this project. Results obtained so far suggest that cactus could be used advantageously in sheep and goat feeding (Ben Salem et al., 1996, 2002a, 2002b, 2002d, 2004). This feed may be used as a basal diet or as supplement of poor quality diets distributed by smallholders to their animals. In both cases, nitrogen supplementation of cactus is necessary. Maintenance requirements of ewes may be overcame by feeding only cactus combined with cereal straws or oaten hay. Cactus may reduce the use of barley grains, which could not be easily purchased by smallholders year round. For example, compared to barley-containing diets, Barbarine lambs supplemented with cactus consumed less straw (320 vs. 515 g dry matter/day/head) and grew at a rate of 81 g/day instead of 110 g/day. Additionally, cactus feeding reduces considerably the consumption of drinking water. The benefits from cactus concern also goat. Indeed, small amounts of cactus (about two pads) and Atriplex (300 g fresh material) were found efficient in increasing by 2.4 folds the average daily gain of local breed goats. In summary, cactus should be viewed as a drought tolerant feed source which may avoid live weight loss of sheep and goats raised under drought/harsh conditions and also a welcome water source in arid zones. Based on energy, these authors concluded that cactus pads might replace barley grains without any digestive disturbance or negative effect on sheep growth.

Impact on feed consumption

In the studied area, during the year 2001/2002, we can note that the cactus consumption reduce mainly the concentrates' consumption in the animal diet although the cactus is quite poor in protein (

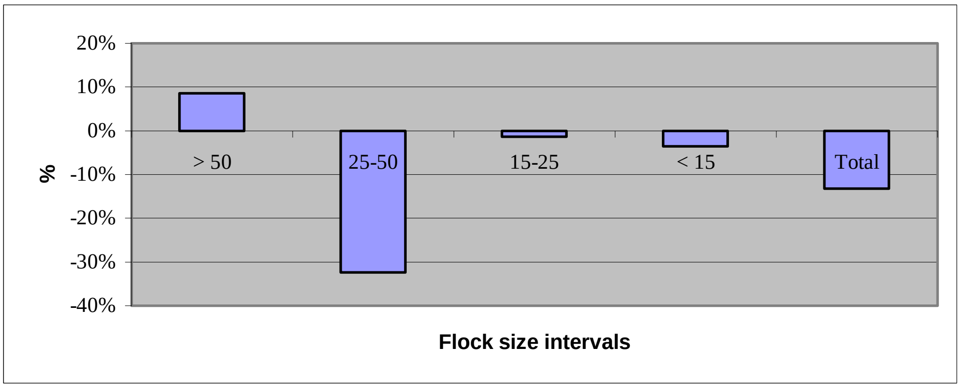
Figure 4). We register also a decrease of hay consumption by a third. The light increase of straw is mainly due to the need to increase straw consumption with cactus.

Figure 4: Variation of feed consumption with cactus per small ruminant unit (in %)



In order to depict feed cost reduction rate according to flock size, the sample of observations is divided according to four flock size intervals (Figure 5). **In average, the feed cost reduction in 2001-02 is around 13.2% per head between users and non users of cactus in the animal diet.** We observe an important decrease of feed cost per head (more than 30%) for the medium herders (between 25 to 50 SR units). These farmers represent 30% of the area planted with the technology. This means that these farmers who have well integrated cactus in the animal diet are more sensitive to the technology. At opposite we observe an increase of 8% of feed cost per head for large farmers. Normally for 1 kg of cactus in the animal diet, the farmers must provide 2 kg of straw or hay to equilibrate the ration. These large herders attempt to respect this equilibrium despite that the straw and hay unit price were threefold increased in 2001/2002 due to the scarcity of these two commodities.

Figure 5: Deviation of feed cost per head with cactus use in the animal diet



The results are more mitigated between adopters and non adopters of the technology. In average, the feed cost reduction on the period 2000-2003 is around 0.16% with one ha of cactus. This is mainly due to the young age of the spineless cactus plantations; majority of these plantations are not yet producing.

6.3. Income effects: from productivity to income variation

Since the technology implemented affects mainly livestock activity, the interest will be granted to the factors that affect the efficiency of this activity. The objective will be to evaluate the productivity gain of the technology introduced at the community level. The income effects have been approached with the cash flow variation at the whole farm level.

Efficiency

In order to evaluate the impact of cactus adoption on the livestock activities related to small ruminants, a stochastic frontier translog cost function was estimated using maximum likelihood technique (Annex 1). As expected, there is a negative relationship between total cost and cactus acreage. Indeed, a one

ha increase in cactus plantation reduces total cost of livestock activity by 0.133 %[2], while an increase of 1 ha in pasture or cereal land (A) reduces total cost of livestock activity by 0.11%.
It is observed that cactus area is saving with both feed and watering and neutral with family labor[3].
Making use of Total Factor Productivity (TFP) decomposition techniques[4], it is possible to evaluate each component contribution to productivity change. The TFP growth reflects the adoption technology advances that facilitate increased output for any given level of inputs. In other words, the growth of TFP is the difference between the growth rate of real output and the growth of real factor input. Efficiency measure approaches the allocative efficiency – that reflects the ability of a farm to use inputs in optimal proportion given a set of prices- and technical efficiency –that related to the ability of a farm to attain maximum output given a set of inputs.
Results are presented in Table 9.

Table 9: Total Factor Productivity Decomposition (%):

	Scale	Total Area	Labor	Cactus	Technology change	Cost efficiency	TFP
1999-2002*	1.0	-4.0	-0.4	1.5	-16.4	0.5	-18.1
2002-2003	2.7	10.4	0.2	1.1	11.8	-21.3	4.9

The period between 1999 and 2002 was marked by a deep TFP decrease of 45 percent. This decrease is a direct consequence of persisting drought which has seriously damaged livestock activity by reducing both factors productivity and reproductive flock size. TFP decrease was mainly due to a decrease of technological change. That is, when drought prevails, purchased feed quantity increases. Drought had caused a shortage in both pasture range land and stubble-field which explain the negative productivity effect of acreages allowed to cereals and pasture. It is worth to underline the decrease in labor productivity during this period. That is, bad weather conditions reduce labor productivity without any off farm opportunities to compensate this decrease.
A 4.9 TFP growth was found for 2002-2003 which was a good year with a suitable rainfall level. It is worth to put the stress on the negative contribution of cost efficiency growth. Indeed, during this period, cost inefficiency has increased by 21 percent. This finding is straightforward: relaxation of some production constraints (such as weather condition in this case) is likely to enhance both technical and allocative inefficiency. Finally, it is clear that positive TFP growth during 2002-2003 is a direct consequence of the amelioration in technological utilization conditions and pasture range land (11.8 percent) and stubble-field productivity (10.4 percent). The good weather conditions have also enhanced labor productivity which explains the 0.2 percent labor productivity increase. Growth in labor productivity during 2002-2003 didn't manage to compensate the decrease during drought period due to the necessary time for livestock output to recover and reach its normal level.
Cactus plantation contribution to TFP growth is found to be positive. Cactus adoption has enhanced productivity growth by 1.5 percent during drought period and 1.1 in good years The low contribution of cactus adoption is mainly due to the fact that till 2003 cactus in alley cropping plantation was still young and thus unexploited. It is expected that cactus acreage ought to contribute effectively in productivity enhancement when plants reach full maturity.

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[2] Coefficients are calculated at the sample mean.
[3] We must be very cautious with these results concerning labor and watering. Indeed, data on these factors have been only estimated in 1999 and 2002 for family labor and watering, respectively, from family composition and occupation and average water need per animal.
[4] $\dot{TFP} = \left[-\alpha_L \dot{L} - \alpha_A \dot{A}\right] + \left[-\alpha_{CAC} \dot{CAC}\right] + \left[(1-e_{cy})\dot{y}\right] + \left[-\dot{TC}\right] + \left[-\dot{CE}\right]$

The equation above decomposes TFP growth to four components: Effect of pasture area (A) and labor (L) (as quasi-fixed factors), effect of cactus plantation (CAC), scale efficiency (y), technological change (TC) and cost efficiency (CE). The first component represents the effect of fixed factors' productivity and autonomous technological change and can be characterized by a downward or an upward shift of the average cost curve according to external conditions. That is, input performance is reduced in the case of bad weather conditions. The scale effect can be characterized by a movement along the same average cost curve to reach a less cost point. Cost efficiency effect is characterized by a vertical shift between actual unit cost and the potential unit cost is based on the average cost function estimate (Jondrow et al., 1982). The cost (in) efficiency measures the monetary gain (loss) of the farmer for one activity compared to the best allocation of inputs and technical choices in the sample for the same fixed asset. Finally, the technological change occurs with a shift in average cost curve. Statistical reliability is presented in annex 1.

Impact on animal stock change

To assess the impact of the technology on the resource endowment, especially livestock, we analyze the evolution of the reproductive capital, especially ewe stock, between 1995 and 2002 (

Table 10). Firstly, with or without the technology, the farmers register a decrease around 35% of their ewe stock following the five drought years (1997 to 2002). It is evident that the technology initiated in 1999 has produced its first effect in 2002/2003. At opposite it is observed a difference between farmers according to the all cactus area (spine and spine less plantation). The farmers using cactus have registered a decrease of 32% of the ewe stock, against 40% for the farmers without any cactus plantation[5]. These results confirm the role of cactus during drought years to limit de-stocking.

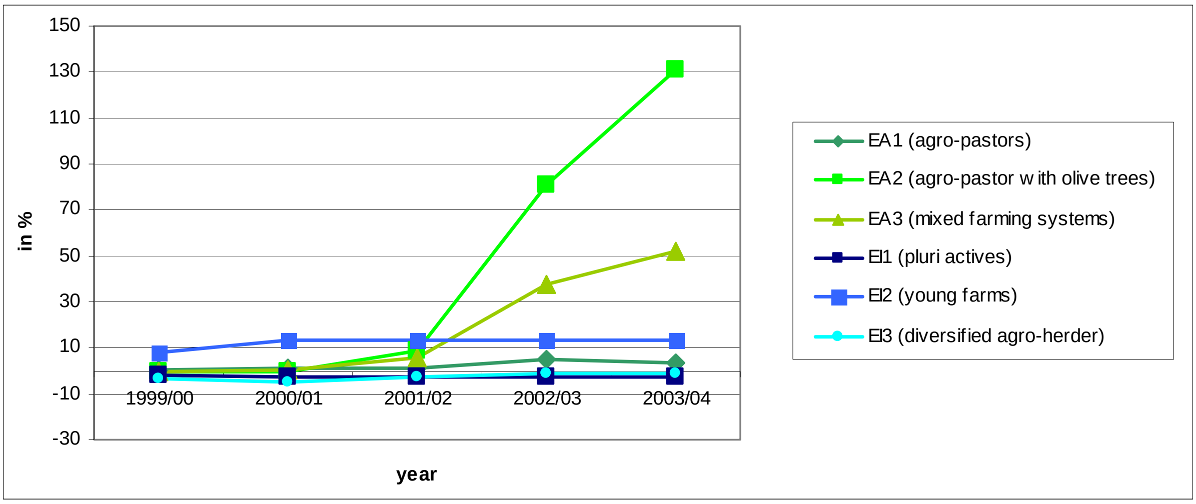
Table 10: Trend of ewe stock between 1995 and 2002 for the adopters and the non adopters (in heads)

Cactus	Ewe stock 1995	Ewe stock 2002	Change (deviation)
Cactus in alley cropping			
Adopters	2784	1797	-35.45%
Non adopters	4223	2749	-34.90%
Total	7007	4546	-35.12%
Total cactus area (with or without the alley cropping technology)			
Cactus	4520	3071	-32.05%
No cactus	2487	1475	-40.69%
Total	7007	4546	-35.12%

Economics impacts at the farm and community levels

To analyze the total impact of the technology at the farm and the community levels, we have used the community model. In the simulation, we suppose that the technology option (spineless cactus in alley cropping) doesn't exist. But the farmers could continue to plant spine cactus in plain. This situation is considered as the counterfactual situation (without the ICARDA project) and it allows estimate the all benefit of the technology at the farm level when we compare with the baseline scenario (with the ICARDA Project). In the Figure 6, line 0 corresponds to the counterfactual situation without the technology and the deviation in % measures the loss or the gain that the farmers have registered with the technology and the institutional actions compared to the counterfactual situation.

Figure 6: Gaps for ewe stock with and without the technology and institutional action (in %)



From this figure, it is noted that the technology has above all benefited to small farmers (EA2, EA3 and EI2), with a ewe capital inferior to 30. For the large farmers (EA1), the situation is different because they had important spine cactus plantations. For the group of diversified small agro-pastors (EA2), farmers could maintain their reproductive capital around 27 ewes, compared to 11 in the

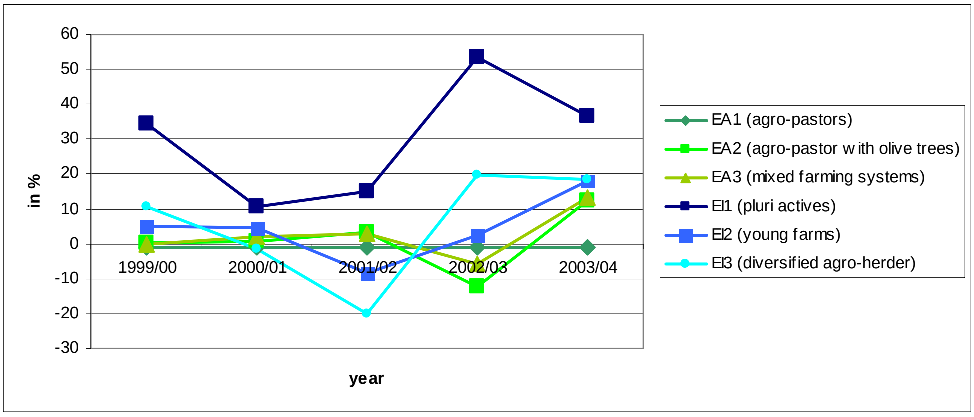
[5] Statistical tests show that this difference is significant.

counterfactual situation. Without including the EA2 that register an important increase in relative value, the annual average ewe capital is 6% more than in the counterfactual situation during all the horizon planning.

So this confirms the role of cactus during drought years to avoid de-stocking.

Figure 7 measures the cash flow' gain at the end of the agricultural year due to the technology compared to the situation without the technology. The Zoghmar community registers in average an increase of 7 % of the annual cash flow. But it is observed a lot of fluctuations and differences between farm types.

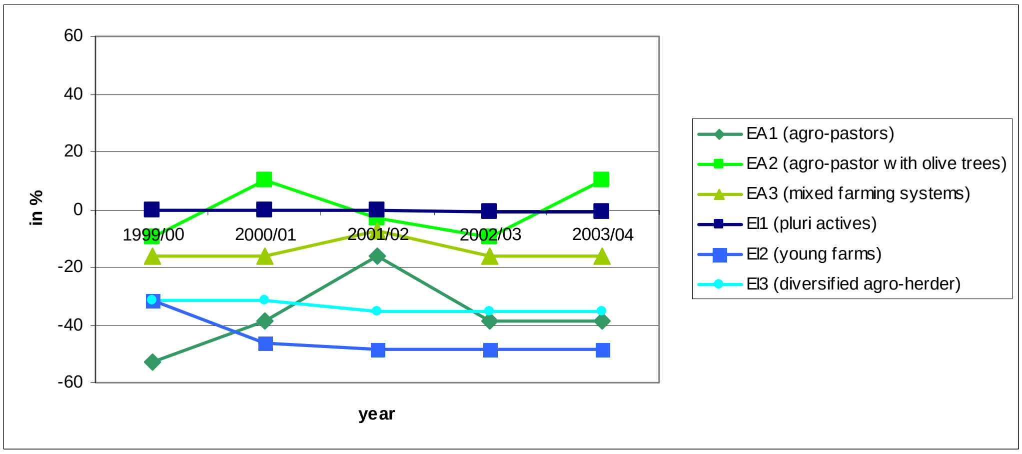
Figure 7: Gaps for cash flow with and without the technology and institutional actions (in %)



To analyze the difference, we must differentiate the farmers who enjoy irrigation from 2001/2002. For EI1, EI2 and EI3, the increase of cash flow from 2001/2002 is partly due to alternative activities as vegetable crops in the irrigated perimeter. For farmers' groups in dry areas (EA1, EA2, EA3), the increase doesn't exceed 1%. This is mainly explained by the maintenance of the flock during the dry years, compared to the situation without cactus. And so the farmers are obliged to buy more feeds than in the counterfactual situation.

One of the objectives of the technology is to make profitable the marginal cereal lands and reduce inefficiency of traditional system of cereal production on marginal lands. Figure 8 shows the reduction of cereals crops on marginal lands with the introduction of the technology. It is registered a reduction of 21% of traditional cereal areas on marginal land. The marginal land allocated to the technology is around 15.7%. So farmers reduce by 5% the traditional cereal areas.

Figure 8: Gaps for cereal areas with and without the technology and institutional actions (in %)



6.4. Distribution effects: Social impacts at the farm and community levels

Our objective is to assess the impact of the technology on the total income distribution at the community level. And it is proposed to compare the changes between 1999 and 2002.

According to the literature, a household is supposed to be poor if a minimum necessary welfare threshold is not attended. The fixation of poverty line here is a corner stone to implement poverty analysis. In the framework of this study, we have used estimations of poverty line values performed by Ayadi *et al*, (1995) for Tunisia. Ayadi *et al*, (1995) have calculated poverty line value for 1990 for the interior rural area among others to which belongs Zoghmar locality. Starting with the value of 1990 and making use of the growth rate of consumer food price index and non-food price index for Tunisia from 1990 to 2002, we were able to approximate the poverty lines for 1999 and 2002 which were found to be 221 and 230 TND per person and per year respectively. It is clear that poverty line estimation represents many shortcomings and must be taken carefully.
In order to assess poverty incidence in the locality, annual expenditure per capita are calculated using all information available in the data survey concerning food and non food expenditure and food self-consumption (cereals and meat). Descriptive statistics on expenditures are consigned in Table 11. Even average expenditure has accused a slight decrease between 1999 and 2002 (first column), average expenditure calculated on the basis of poor households' data has increased (column 3).

Table 11: Descriptive statistics on the household expenditure (in TND)
(Sample: 40 households surveyed in 1999 and 2002)

	Average expenditure Total sample	Median Total Sample	Average expenditure for poor	Standard deviation Total sample	Standard deviation For poor	Median For poor
1999	332	273	206	154	157	161
2002	330	272	211	156	132	181

Three poverty indicators are calculated in order to understand the change in situation between 1999 and 2002: Head count (H), Poverty Gap (PG) and Sen poverty indicator (S) (Sen, 1976). The results are consigned in Table 12. The head count index implies that poor household proportion in the sample has slightly increased between 1999 and 2002. This increase is almost non significant and therefore it can be argued that the proportion of poor households in the sample has been stable between the two dates. The poverty gap (PG) index implies that the gap between poor household expenditure and poverty line has been substantially reduced between 1999 and 2002. That is the improvement of quality of live for those who are labeled as poor households. Sen Poverty indicator confirms results of PG index. Indeed the great difference between the values of 1999 and 2002 are due to the fact that this measurement take into account *H*, *PG* and the Gini concentration index calculated using poor households' distribution. The concentration among poor households' expenditure (S) has been significantly decreased between 1999 and 2002.
In order to evaluate income distribution among the community, Gini concentration index is calculated based on the data sample for 1999 and 2002 (Table 12, column 6). It is worth to underline the low level of Gini indexes for the two period times. That is income distribution among Zoghmar locality's households seems to be relatively egalitarian. Comparison of 1999 and 2002's Gini indexes implies that no significant changes in income distribution have been recorded.

Table 12: Poverty indicators and expenditure distribution

	Poverty line	Head count (H) (in %)	Poverty Gap (PG)	Sen poverty indicator (*100)	Gini coefficient	Gini concentration index
1999	221	20.00	11.01	**4.28**	0.245	0.117
2002	230	20.51	4.94	**1.86**	0.241	0.043

Therefore, poverty analysis shows that, despite the hard climatic conditions during the analysis period (1999 to 2002), poverty intensity had been reduced. Different factors may explain this reduction of poverty intensity after 5 years of drought: 1) the diversification out of agriculture; 2) the new agricultural alternative such as fattening which is less sensible to climatic conditions; 3) and, at a low level, to the resort to low cost input such as cactus. Because we observe in the field that during these dry years, farmers have sometimes overgrazed the new cactus plantations in order to face feed shortage.
However these results are surprising. We have seen that farm size is a key constraint to adoption. And this should have significant implications for the impacts of the technology on income distribution with an increase of Gini coefficient. But if the adoption of cactus in alley cropping concerns mainly the

large agro-pastors, the majority of farmers (including the small ones) had used cactus pad during this period. And it is difficult to isolate each effect: the adoption of the technology in term of plantation and in term of using in the feed practices.
The model confirms that the technology has slightly increased the inequity (Table 13). It is true that the large farmers such as the groups EA1 and EI1 represent 9.7% of the sample and they have planted 72% of the area with the technology considering that the group EI1 plants 30 ha.

Table 13: Trend of GINI coefficient in the Zoghmar Community (Central Tunisia)

	1999/00	2000/01	2001/02	2002/03	2003/04
Reference with project	0.28	0.28	0.31	0.29	0.31
Counterfactual	0.28	0.27	0.31	0.26	0.29

In order to evaluate the impact of social factors in Zoghmar locality, sample farmers are clustered according to their social fractional belonging. Each fraction corresponds to the dominant enlarged families in the community and can be considered as social entities. Eight broad families are identified[6]. The objective of this analysis is to capture some inequalities between social fractions knowing that innovation increases often social inequalities.

Table 14: Impact of fractions belonging on the degree of inefficiency

Total panel (balanced) observations: 45;
Z, M, B, MH, R, H, C: the abbreviations of the social fractions.
Degree of inefficiency is calculated (see 6.3)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Intercept	1.130711	0.087332	12.94727	0.0000
Z	-0.056243	0.087362	-0.643797	0.5237
M	-0.333946	0.265299	-1.258754	0.2160
B	0.047841	0.136319	0.350953	0.7276
MH	-0.371167	0.093610	-3.965059	0.0003
R	0.424347	0.107396	3.951242	0.0003
H	0.369899	0.138292	2.674768	0.0111
C	-0.149482	0.095073	-1.572283	0.1244

Two social fractions (R and H) have negative impacts on the degree of efficiency (Table 14). These two fractions correspond mainly to agro-pastoral systems or mixed farming systems with an important livestock activity. But these two groups haven’t benefited from the OEP project to implement cactus in alley cropping, expect one farmer in each fraction. Besides, the group C who registers positive impact on the degree of efficiency has well benefited of the project. It is difficult to explain the case of the group MH who count only three farmers.
So this analysis would confirm the role of cactus to improve efficiency of livestock activity. But we must be very cautious because all of them have spine cactus or sometimes spineless cactus in lines, the old technology which has been developed in the mid-nineties. Otherwise the repartition of cactus plantation showed unequal geographical repartition of cactus in the community (plate 1). This is mainly due to soil type and land management. The large plots with the possibility to implement the technology are mainly located in the North East. This explains a part of social inequity.

[6] In order to preserve confidentiality, family names are encoded.

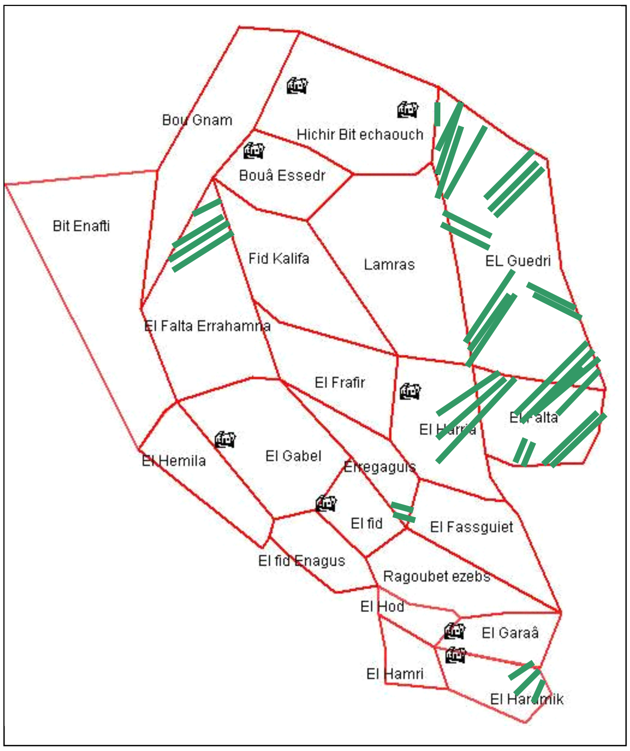


Plate 1. Cactus plantation represented on a GPS plotting of Zoghmar community with the borders of toponymic areas and location of main « douars ».

: area implemented by OEP with the technology

(Toponymic: social-geographical unit)

Source : M&M project (ICARDA), OEP

6.5-Agregate environmental impacts

Impact on soil conservation

Planting cactus on marginal lands improves soil characteristics (Table 15). Monitoring organic matter, carbon, phosphorus and K contents of soil samples shows that planting cactus improves soil nutrients, especially for organic matter, carbon and P with relative increases of 350%, 450 % and 100 %, respectively. These increases follow more the same trend when compared to marginal land cropped to barley without fertilizers application. Cropping barley between cactus lines reduces the amount of nutrient and values recorded are very similar to those obtained with eroded rangeland cropped or not with barley. It looks like that the nutrients made available by cactus planting are used by barley crop, and may explain, in addition to “wind breaks” and “niche” effects, the significant increase in cereal yields.

Table 15: Soil nutrient changes between the different treatments (5 plots)

	Natural rangeland	Barley	Cactus without barley	Cactus with barley
Sample	C439	C440	C441	C442
Total calcaire %	17	23	12	11
Calcaire actif	1	6	1	1
Organic matter (%)	0.4	0.7	1.8	0.2
Carbon (%)	0.2	0.4	1.1	0.1
P_2O_5 Assim ppm (Olsen)	13	13	26	15
K_2O Assim/1000	0.07	0.08	0.23	0.48

Besides we observe two opposite effects of cactus with the technology: 1) soil enrichment in potassium and 2) soil exhaustion in calcareous. Cactus is known to be rich in calcium and quite poor in potassium. The increase of active calcareous with barley is explained by the low content of calcium in barley products, compared to cactus but also herbaceous species in the rangelands.

Measurement of water use efficiency

With no on farm trial during the project, the measurements of Water-Use Efficiency (WUE) come from the literature. De Kock (1980) reported productions of 1 Kg DM per 250 Kg of water in the Karoo of South Africa, while Le Houérou and El Barghati (1982) obtained 300 Kg of water for each Kg of above ground DM produced in the steppes of Northern Africa. These correspond to WUE's of

4.0 and 3.3 mg DM g-1 H2O, compared to about 1.0 for Lucerne, 1.3 for wheat, 1.4 for barley and 0.5 for common un-degraded range.
However, the most outstanding fact is the very high WUE and RUE under arid conditions, or with low water inputs. RUE's and WUE's of the same order of magnitude as those found for cacti can be achieved with C4 plants such as pearl millet, sorghum, maize, elephant grass, guinea grass or sugar cane, but water consumption is then three to five times higher in absolute terms, in other words those have little drought-tolerance, contrary to cacti (Nobel et al., 1992). This trait makes cactus, agaves and saltbushes true "arid-zone fodder crops". Cacti and saltbushes are, in addition, ideally complementary both in terms of feed composition, feed value and in terms of soil requirements. Saltbushes are rich in nitrogen while cacti and agaves are rather poor, cacti require rather light or sandy soils, while most saltbushes need salty to loamy soils (either saline or not) (Le Houérou, 2002).

7. EX ANTE IMPACTS

7.1. Benefit-Cost Analysis

The indicator of internal rate of return (IRR) is often used to approach the economic or financial profitability of one project. This analysis doesn’t take into account the social and environmental impacts due to the lack of follow up in the time as if some environmental effects are indirectly included in the productivity gains of barley and pasture.
In Tunisia, cactus may be planted individually by private farmers but for the majority it is planted with Livestock and Pasture Office (OEP) support within de national program that forecast to implement around 96 096 ha in spine less cactus in alley cropping before 2011. The average life duration of a cactus plantation is around 22 years that will be considered as the assessment period. We assume that only cactus pads are collected; fruits are not considered even they are used for self-consumption and hence improve people diet or marketed. We consider two scenarios for enhanced values of pads: 1) with market: the pads are sold 0.040 DT each, 2) without market: the pads are estimated with their energy equivalent (forage unit) compared to barley grain. We suppose that cactus plantation gives the first production the fourth year with 40% of the potential yield. The production is 60% the fifth year and 80% the sixth year until reaching the full production the seventh year. Cereal and pasture biomass achieve their full production with the technology the seventh year.
Two types of research cost are estimated: 1) the development cost research included in the ICARDA project in collaboration with the national research institutes for the 4 years (1999-2003); 2) the extension cost research that corresponds to the minimum research cost before implementing the technology out of the study area.
The IRR is calculated at the national level for the OEP project that concern around 96 096 ha and 13 500 farmers (Table 5). We suppose Gamma distribution for the yields of barley, cactus and pasture.

Table 5: The IRR results

	Scenario	Min	Mean	Max
Barley/cactus system	P=0.040	0.46%	14.7%	36.6%
	P=0.012	-0.78%	4.1%	15.5%
Pasture/cactus systems	P=0.040	0.95%	15.7%	37.4%
	P=0.012	-1.2%	4.7%	16.5%

The high rates of IRR with pad market show the high expected profitability of the project if there is a public effort to implement a market for pads. But we observe a high sensitivity of the IRR according to climatic and agronomic risks.

Considering the hypothesis on climatic change, the pasture land produces around 370 UF to 500 UF per year[7]. With a unit price of 0.17 DT/U.F., the product is estimated from 62.9 to 85 DT/ha. The observed yield of pasture in alley cropping reveals a production of 4.98 tons/ha or 1245 kg dry matter per ha in a good year, compared to 825 kg in natural rangelands. So we obtain an increase of 50% of biomass on pastureland thanks to the technology. The results are quite spectacular for these very degraded lands. Very few projects could register an IRR around 15% on these lands.

[7] U.F.: Forage Unit based on the energy of 1 kg barley grain.

7.2. Approach of market responses

In a new set of simulations, the opportunity to sell the pads' production either at the community level (M1) or at the national level (M2) was introduced in order to simulate the impact of market opportunity on the technology adoption and technology impact. We suppose that the national demand could absorb 20% of the community production. In the scenarios (M3) and (M4), we compare the impact of market in a context of liberalization. In (M3), we suppose the liberalization of barley and meat markets with random fluctuation of prices with more or less 15%. In (M4), we induce the alternative to sell 20% of the production on the market. Table 16 and 19 show the impacts of the organization of pads' market on the ewe stock (live-stocking) and the cash flow (welfare of farmers).

Table 16: Variation of ewe stock for the different scenarios of markets (in % of deviation from the reference with no market) (Tunisia)

	M1	M2	M3	M4
	Community market	Regional market that absorbs 20% of the supply	Liberalization on meat and barley sectors	Liberalization + Regional market that absorbs 20% of the supply
EA1	23.07	22.76	-20.08	23.39
EA2	44.33	43.20	6.22	54.94
EA3	68.48	68.96	17.24	116.45
EI1	-4.87	0.00	0.00	0.00
EI2	-1.57	2.17	-2.05	3.27
EI3	0.00	0.00	-2.87	-9.75

Table 17: Variation of cash flow for the different scenarios of markets (in % of deviation from the reference with no market) (Tunisia)

	M1	M2	M3	M4
	Community market	Regional market that absorbs 20% of the supply	Liberalization on meat and barley sectors	Liberalization + Regional market that absorbs 20% of the supply
EA1	9.24	22.35	45.11	34.39
EA2	11.23	11.83	0.80	13.16
EA3	21.66	21.58	2.61	20.47
EI1	-14.47	9.15	-2.46	0.57
EI2	-28.49	-0.38	-3.28	-4.37
EI3	3.58	11.36	1.62	10.36
Community	**15.30**	**18.32**	**5.14**	**18.36**

The four scenarios seem interesting for the farms types without irrigation, except the scenario of liberalization (M3). All the farm types without irrigation (EA1, EA2, EA3) increase their flock size and register a positive progress of their cash flow. It is different for the farm types with irrigation that become potential buyers in the case of the organization of a community market. This explains a reduction of the Gini coefficient from 0.33 to 0.25 owing to this community market.
In the scenario (M3), the liberalization leads to a great de-stocking for the agro-pastoralists (EA1). The main handicap for them is the price fluctuations of barley because these farmers are net buyers. But, the possibility to sell pads' production could avoid this negative impact in a context of liberalization (M4). Besides, the small and medium farms with irrigation (EI2 and EI3) increase their cactus area.
Therefore, the organization of a market for cactus products will have profitable impacts on the different farm types as if few farmers increase their area. It would stimulate live re-stocking and slow down the effects of prices fluctuations in a context of liberalization.

7.3. Attempts of Scaling up

During the period 1990-2003, 104,162 ha have been planted in cactus with this incentive with an average of 8000 ha/an in Tunisia, especially in North and Central Tunisia. But the technology of cactus in alley cropping represents 45% of the total planted area (or 52,081 ha). The new strategy (2002-2011) forecasts to extend the technology of cactus in AC to 44,000 ha. The total subsidies for the technology which cover the implementation cost are valuated to 8,495 DT for the period 1990-

2003 and the compensation to 4,382 DT. On the basis of 6.5 ha of cactus per farm (according to the OEP program in the Zoghmar Community), around 6770 farmers will be concerned. Totally on the period 1990 to 2011, around 13500 farmers could have benefited of the technology (without taking into account the farmers who implement this technology without OEP support) on a total area of 96 081 ha minimum on alley cropping. The total support (based on 395 DT/ha) is estimated around 37.9 millions DT.

With an increase of more 50% of barley grain yield, farmers would have used more than 150 kg of ammonitrate per ha. So we have an economy of more than 3.17 millions DT of fertilizer for the farmers (Table 18). Similarly, we observe a feed cost reduction of 5.64 DT/head with the cactus. If we suppose 30 heads in average per farm, we have a reduction of total feed consumption of 2.5 millions of TD. The results are more spectacular for cereal. If we suppose that all the improved lands with cactus are conduced with barley in alley cropping, the surplus for only one year could be around 30 millions TD in a good year.

Table 18: Estimation of supplementary saving and receipts thanks to the technology at the national level

	Supplementary saving		Supplementary Receipts		
	Fertilizer	Feed	Cereal grain	Cereal straw	Pasture
Quantity	150 kg/ha	5.64 DT/head	1.4 T/ha	0.49 T/ha	1.68 T/ha
Total quantity	14 412 tons		134 513 T	47 560 T	
Saving in millions DT	3,17	2,5	25,55	4.7	

As if these estimations are quite rough, they give information about the interest of the technology at the national level.

9. CONCLUDING REMARKS

1. The different methodologies used in this study allow capturing different impacts of the NRM technologies in the community. A key finding is that farm size is a key constraint to adoption but this hasn't the expected impact on income distribution knowing that the main benefit from the technology provides from the use of cactus in the feeding system. And it is not exclusive to adopters. But the impact assessment results give information of the technology impact at different levels:

1. At plot level:
    - Increase of barley yield and total biomass as well as plant cover on eroded marginal lands (micro-environment effect)
2. At livestock level:
    - Reduction of purchased feeds, less market dependence
    - Reduction of total feed cost around 13.2% per farm
3. At economic efficiency level:
    - Negative relationship between total livestock expenditure and cactus acreage
    - Reduction of inefficiency especially during dry years.
    - Reduce of de-stocking pressure during dry years
4. At farm level
    - Increase of cash flow by 7 %
    - Reduction of cereal cropping on marginal lands during dry years by 5 %
    - Reduction of livestock de-stocking by 6 %
5. At social level:
    - Reduction of poverty gap for the poor group
    - No change of total distribution income (Gini around 0.24)
6. At environmental level:
    - Improvement of soil nutrients (OM, C, P, K) with cactus
    - Increase of plant cover, which will probably lead to a reduction of soil losses.

The results confirm also that agricultural-policy change does not seem to be necessary enabling condition for the new technology diffusion. For this technology, the pad distribution may be more crucial than the compensations in the adoption process. But, without pad market, the subsidies may be important in the investment period. Then, there is a need to focus more on marketing potential of the new technologies being introduced, including the export market for cactus fruit.

2. From a methodological point of view, these first results show that a dynamic and recursive mathematical model could be used in an ex post impact assessment. But important features must be addressed in these approaches to improve the assessment of NRM research. The dynamic and recursive process is complex for natural resource management knowing that bio-physical process (such as erosion, water saving) are long-time compared to farmers' decisions that suit to agricultural & livestock process and family objectives. And the environmental and sustainability issues of concern go over the household level and exceed generally the community. Important improvements could be done to integrate these multi-scale effects.

Integrating environmental and socio-economic parameters is central to NRM researches to approach the complexity of these systems and their capacity and degree of adaptation, viability and sustainability at long term. But biophysical model such as SCUAF requires important data on nutrient cycles, soil quality over times. The first measurements on soil and plants must be validated at least at the community level or regional level and take into account the spatial and temporal changes.

In summary, this study on NRM impact assessment offers interesting hypothesis to continue the valuation process, especially the environmental impacts. Moreover the young age of the plantations make difficult to have a good appreciation of all the benefits that can be expected from the technology. Only an adapted monitoring of some indicators over times (at least 5 years of full production) could confirm these results and validate the interest of the technology at the different scales of analysis.

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Annex 1
Productivity and Efficiency

In order to evaluate the impact of cactus adoption on the livestock activities related to small ruminants, a stochastic frontier Translog cost function was estimated using maximum likelihood technique. Data used to fulfill this task are the (unbalanced) panel data of 45 farm households from Zoghmar community. The cost function presented in 5.3 is specified as:

$$\begin{aligned}\ln C_{kt} &= \alpha_0 + \sum_i \alpha_i \ln w_{kit} + \tfrac{1}{2}\sum_i\sum_j \alpha_{ij} \ln w_{kit} \ln w_{kjt} + \alpha_L \ln L_{kt} + \sum_i \alpha_{Li} \ln L_{kt} \ln w_{kit} \\ &+ \alpha_y \ln y_{kt} + \alpha_t t + \tfrac{1}{2}\alpha_{tt} t^2 + \sum_i \alpha_{ti} t \ln w_{kit} + \alpha_{tL} t \ln L_{kt} + \alpha_A A_{kt} + \alpha_{CAC} CAC_{kt} \\ &+ \sum_i \alpha_{CAC,i} CAC_{kt} \ln w_{kit} + \alpha_{CAC,L} CAC_{kt} L_{kt} + \alpha_{CAC,t} CAC_{kt} t + \varepsilon_{kt}\end{aligned} \tag{1}$$

Where: subscripts *k*, *i* and *t* stands for farm-households, inputs and time respectively. *C* is total cost of livestock activity, w_{it} are prices. In the table A1, it is distinguished the price of feed (*pf*) and the price of water (*pw*). Labour (L) (including family, casual and hired labour) is introduced into the model as a fixed factor. A time trend is introduced into the model in order to assess for autonomous technological change. To examine the impact of cactus adoption on the productivity, total acreage of cactus plantation (*CAC*) is included to allow for a possible shift on the total cost. The cost of purchased feed for livestock is naturally affected by the resource endowment of household such as acreage allowed to cereals. That is the reason leading to include total acreage allowed to cereals and accessible pasture areas (*A*). The choice of acreage allowed to cereals rather than produced quantities of cereals is driven by the fact that, often (even when drought prevails), acreage allowed to these crops is fructified by its conversion to a pasture. The significant estimated coefficients of the cost function are displayed in table A1.

Table A1 - Stochastic cost function estimates

Var.	**coefficient**	**t-ratio**	**p. value**	Var.	**coefficient**	**t-ratio**	**p. value**
Cte	21.795	23.911	0.0000	**pfpw**	-3.094	-8.276	0.0000
Y	0.881	8.533	0.0000	**Pfl**	0.025	0.039	0.9689
P feed	-1.495	-16.468	0.0000	**pfcac**	-0.109	-9.908	0.0000
L	-1.738	-2.175	0.0322	**Pwl**	-0.315	-1.055	0.2941
Pw	-5.031	-5.568	0.0000	**pwcac**	-0.014	-11.437	0.0000
A	-0.115	-1.510	0.1345	**Lcac**	0.001	0.057	0.9547
CAC	-0.135	-0.594	0.5538	**T**	-1.030	-1.231	0.2216
$1/2pf^2$	5.891	8.391	0.0000	**$1/2t^2$**	-0.477	-1.900	0.0606
$1/2l^2$	0.617	1.485	0.1410	**Pft**	-1.173	-2.378	0.0195
$1/2pw^2$	0.091	0.467	0.6417	**Pwt**	0.369	2.023	0.0460
$1/2cac^2$	-0.001	-1.606	0.1116	**Lt**	-0.050	-0.352	0.7254
				cact	0.004	0.049	0.9611

Two components in the deterministic side of the cost function are the most important for the purposes of this study, i.e. flock size effect (Y) and cactus plantation effects, respectively on water (pwcac) and feed cost (pfcac). The negative relations between cactus area and feed or water cost show that the increase of cactus area is feed and water-cost reducing. The cost elasticity of flock size (*Y*) was significant and equal to 0.88. The null hypothesis of constant return to scale is strongly rejected beside the increasing return to scale hypothesis. That is livestock activity in Zoghmar locality is below its least cost level.

Annex 2

Main equations of the mathematical programming model

1. Cropping system

The cropping system depends on the different possible and known alternatives at the community level: cereal crops (durum wheat, grain barley), vegetable crops (tomato, cucumber), fodder crops (vetch, oat, sorghum) and the perennial crops (olive trees, fruit trees, Cactus and Atriplex). The vegetable crops, the fodder crops such as oat and sorghum and the fruit trees are only practiced in irrigated areas. Perennial crops are characterized according their age and the land type (irrigated, dry or pastureland areas). For each crop, farmer can choose different technological packages (local or improved seeds, fertilization, tillage). The expected yield will depend on the technique used, the climatic conditions and the soil types (irrigated, rainfed areas or rangeland). So the allocation of land between each crops is written as follows:

$$\sum_{Csa,tech} TERS_{csa,tech,ex,ye} < SDISP_{ye,ex} - \sum_{csp,tech,age} TERPLS_{ye,csp,tech,age,ex} - \sum_{ox} LOCOUT_{ye,ex,ox} + \sum_{ox} LOCIN_{ye,ex,ox}$$

With *Csa* : the annual crops possible for each soil type (*s*) ; *tech* : the technical choice (type of tillage, local or improved seed, fertilization, phosphorus use); *ex:* type of farms; age: age of the plantation. The allocation the land (*TERS*) between the different crops cannot exceed the availability of land (*SDISP*), less the land planted (*TERPLS*) or the land rent out (*LOCOUT*), plus the land rent in (*LOCIN*). The lands rent in or out are always exchanges at the community level. In this community, the transactions of land (sell/purchase) are uncommon.

2. Livestock system

Stock animal changes every season and every year according to sale (SOLD) and purchase (PUR) decisions and demographic parameters (mortality, reproductivity, fecundity, natural growth). For small ruminants, animal are followed each 3-months stage. In the model, the possibility to practice fattening is taken into consideration. Fattening is mainly practiced during the Aïd[8] period. Short fattening begins in autumn with yearly sheep (between 9-15 months old) and finishes in winter and long fattening begins in spring with lamb (5-6 months old) and finished in winter during the Aid period. At each stage and each period, the farmers may decide to sell or purchase. Only the no-weaned animals are not marketed. For young cows, the classes of age are each 6 months.
So the animal stock per category is written:

$$Eff_{ex,ani_i,s,ye} = Eff_{ex,ani_{i-1},s-1,ye} * (1 - Mort_{ani_{i-1}}) + PurchAni_{ex,ani_i,s,ye} - SellAni_{ex,ani_{i-1},s,ye}$$

With *Eff*: animal stock of the specie (*ani*) and the age (*i)* during the season (*s*) and the year (*ye*); *Mort*: the rate of mortality for the specie (*ani*) at the age (*i*); *PurchAni*: the purchase of animal during the season and *SellAni* the selling of animals. We suppose that the decisions of selling of animals are taken at the end of each season and the decision of purchase at the beginning.
For the lambs produced in the farm, fecundity and prolificacy rate per ewe are determined from the collected data on the farm. The main lambing season is autumn-beginning of winter.

3. The feeding system

The feeding strategy is specified according to animal type, sex, age and nutritional requirements (dry matter, digestible nitrogenous matter and energy content expressed in Forage Unit) for the different physiological stages. The constraints included one set for the minimum requirements in terms of energy and protein and one set for the maximum/minimum requirements for dry matter. The minimum or maximum requirements are determined through the zootechnical analysis of the feeding practices (INRAT, M&M Tunisian Team, FAO).

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[8] Aïd : an annual Muslim ceremony where yearly lamb are sacrificied

The formulation is:

$$\sum_{c,prod} Consani_{ex,c,prod,s,ye} * Nutprod_{c,prod,nut} + \sum_{con} Conc_{ex,con,s,ye} * Nutprod_{prod,nut} \geq \sum_{ani_i} Eff_{ex,ani_i,s,ye} * Besnut_{ani,nut}$$

With *Consani* : the consumption of agricultural products or by-products (straw, stubble) name *prod* from the crop (*c*) ; *Nutprod* : the composition of the products (*prod*) in dry matter, energy and protein (*nut*); Conc: the consumption of each type of concentrates (*con*); *Eff* : the animal stock and *Besnut* : the requirements of animals in each nutrient (nut).

Different constraints are written to describe the main practices of farmers in the area:

- cactus fruit cannot exceed 5% of the dry matter content
- cactus pad cannot exceed 50% of the dry matter content
- for each kg of cactus pad, 2 kg of straw and hay must be brought
- the detritus of olive tree can not exceed 30% of the dry matter content
- The barley grain is comprised between 15 and 60% of the dry matter content and 80% for fattened lambs
- Straw cannot exceed 40% of the dry matter content
- The stubble cover less than 15% of the feed ration
- The feed blocks are limited to adults
- Farmers give as much as bran than barley grain to stimulate the milking

Nutrient composition tables are used for the main sources of feed, which are produced on the farm or purchased from the market or accessed through monetary or non monetary contractual arrangements. In addition, private resources endowments are taken into consideration along with technical, market and institutional constraints.

The total diet (except concentrates) comprises produced and purchased feed. The production can be consumed (*CONSANI*), stocked (*STOCKEND*) or sold (*SOLD*) to the market. The total consumption of fodder resource is based on the past stock (*STOCKINI*), the new stock and the purchases (*ACHAT*). So the new stock is written as:

$$\begin{aligned} STOCKEND_{ex,c,prod,s,ye} &= STOCKINI_{ex,c,prod,s,ye} + RECOLT_{ex,c,prod,s,ye} \\ &- CONSANI_{ex,c,prod,s,ye} + ACHAT_{ex,c,prod,s,ye} - SOLDP_{ex,c,prod,s,ye} \end{aligned}$$

For the non storable feeds (stubble, cactus pad, and green fodder), the purchase and sell are realized at the community level.

4. Socio-economic and biotechnical linkages

The biotechnical system is completely linked to the economic constraints and opportunities. The cash flow is necessary positive. The main incomes are the sale of agricultural products, animals sale and off-farm incomes. The main expenditures are variable costs for crops, the feed purchase, labour salaries, and other charges as veterinary and watering charges. A set of constraints allow to approach the distribution of family labour between farm and off-farm works and each farm can use external salaries. Farmers can obtain short term credits or long term credits. Short term credits are limited according to the owned land in rainfed or irrigated areas. Medium term credits (5 years) must be reimbursed each year with constant annual annuity and the amount is function of the investment. We have introduced a third source of credit, the informal credit that intervenes at the community level. The maximum amount is fixed according to the data for each farm types. At the end of each season, the surplus is either re-invested in the farm or saved at the interest rate of 3 %.

The receipt (*RECEIPT*) comprise the sale of animal and vegetable products (including animal by product such as manure, wood, milk), the incomes from service (rent of land), the economic support (as the subsidy) but also salaries or incomes from other non agricultural activities or agricultural salaries; the expenditure (*EXPEND*) concern all the operational charges (seed, fertilizer, manure, purchased feed, veterinary expenditure, labour, rent in, irrigation), the purchase of animals, the cost of tree plantations (implantation or uprooting). To these traditional transfers, it is added the contracted credit in the season near the bank (*CREDCT*) or the friends in the community (*CREDAMI*), the reimbursement of loans (*LOANIN*), cash of the previous season ($CASH_{s-1}$) and deduced the reimbursement of credit plus the interest and the new community loan (*LOANOUT*).

$$
\begin{aligned}
& CASH_{ex,s,ye} = RECEIPT_{ex,s,ye} - EXPEND_{ex,s,ye} + CASH_{ex,s-1,ye} \\
& + CREDCT_{ex,s,ye} + \sum_{ox} CREDAMI_{ex,ox,s,ye} + LOANIN_{ex,s} - CREDCT_{ex,s-2,ye} * (1 - Ti) - LOANOUT_{ex,s}
\end{aligned}
$$

To these traditional transfers, it is added the variation of stock for animals and storable agricultural products and it is deducted the saving, the fixed charge, the private consumption (family consumption in cereal and animals) and the capital for investment in order to calculate the net income (REV). The investments in plantation (like cactus) are funded by self-funds, subsidies and medium term credit. For cactus, the subsidies cover 100% of the implementation in 1999. For animal stocking, there are no subsidies.

In the decision process, the articulation and arbitration of short term decisions ought to be consistent with medium term objectives or strategies. However, the static model cannot allow approaching the decisions of investment at medium and long term. If the decisions are often taken at short term in dry area in order to reproduce the farm and ensure the minimum social and economic requirement of the household, it is difficult to understand the decision of investment in perennial crops or livestock without taking into account the strategies at medium and long term. Most of the time, technology introduction need time and a multi periodic model could approach the decision process of the farmers.
It is then supposed that the farmers take their decisions to maximize the disposable net income plus capital (livestock +plantation) over the planning horizon, called the planning period. This horizon is defined according to *portfolio theory* (Boussard, 1971). In other term, it is chosen so that the consequences of the decision beyond the planning period don't affect the decision making during the planning period. The multi period model allows joining and analyzing the articulation of decisions during the planning horizon.

The community model constraints concern the location of land and the non storable feed transactions (including common grazing of stubble).

<u>5. Risk consideration in the model</u>

The decisions are taken in a risky environment. As everywhere in the world, the farmers must face climatic perturbations that affect the forage production; in a liberalized economics, the price can fluctuate due to climatic or economic changes. Farmers take theirs decisions in order to face different perturbations and ensure the viability and stability of their farming systems. It is assumed that yield and price can fluctuate in a random way and the farmers decide their farm management in order to avoid catastrophic situation. This situation will depend on the personal behaviour of the farmer (some farmers are less or more averse to risk), but also on the actual economic and bio technical results. A farmer in a comfortable situation can take more risky decisions than in a small farm, etc. The risk taking is formulated under the Target Motad approach proposed by Tauer (Tauer, 1983) and the function is written as:

$$\text{Max } E(Z_{ex}) = \sum_{ye=t_0}^{T} \frac{C_{ye} X_{ye}}{(1+\tau)^{ye}} + \mathbf{K}/(1+\tau)^{T} \text{ Avec : } A X_{ye} \le B_{ye} \text{ ; } B_{ye} = bX_{ye-1} \text{ ; } X_{ye} \ge 0$$

Under risk constraints :

$$T - \sum_{j=1}^{n} C_{ye,j,r} \bullet X_{ye,j} - \lambda_{ye,r} \le 0 \text{ ; } r = 1,\ldots,s \text{ ;}$$

$$\sum_{r=1}^{s} P_r \lambda_{ye,r} = \Omega \text{ ; } \Omega = M \rightarrow 0 \text{ ;}$$

$$X_j \ge 0, \lambda_{ye,r} \ge 0 \text{ ;}$$

where E(Z) is the objective function for maximizing, C_{ye} the vector of expected income from productive activities in the year (ye), X_{ye} the vector of activities' level, T the minimum target income, Ω Risk aversion coefficient according to Target MOTAD method, λ_{ye} the sum of negative deviations related to the income threshold (fixed for each farm type), T the planning horizon, τ the discount rate, A the input/output matrix and B_{ye} the matrix of available resources that depend on decision in the previous season (ye-1).

Farmers in the community model have been grouped into farm types (*ex*). We have maximized a weighed net income function where the weights α_{ex} represent the importance of each farm type (the frequency of which is n_{ex}) in the sample or population of size *N*. Therefore the function is written:

$$MaxTZ = \sum_{ex}^{h} \alpha_{ex} E(Z)_{ex}$$

$$\alpha_{ex} = \frac{n_{ex}}{N}$$

h is the number of clusters chosen according to the distribution of farm types at the community level.